ANALIZA MERA ZA UŠTEDU ENERGIJE POTREBNE ZA ZAGREVANJE POSTOJEĆE STAMBENE ZGRADE

ANALYSIS OF ENERGY SAVING MEASURES FOR AN EXISTING RESIDENTIAL BUILDING

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U okviru ovog rada izvršena je analiza implementacije mera uštede energije postojeće stambene zgrade. Simulacija energetskog ponašanja stambene zgrade, korisne grejne površine od 1247,68 m^2, je sprovedena upotrebom softvera EnergyPlus. Šest predloženih mera je analizirano: zamena prozora i vrata (slučaj 1); izmena krovne konstrukcije (slučaj 2); izmena konstrukcija poda na zemlji i međuspratnih konstrukcija (slučaj 3); izmena unutrašnjih zidova između različitih korisnika (slučaj 4); izmena unutrašnjih zidova ka negrejanom prostoru (slučaj 5) i implementacija svih prethodno pomenutih mera (slučaj 6). Rezultati simulacija ukazuju da su prosečne uštede toplotne energije analizirane zgrade, respektivno: 12,71% (slučaj 1); 9,35% (slučaj 2); 5,2% (slučaj 3); 0,56% (slučaj 4); 2,04% (slučaj 5) and 29,37% (slučaj 6). Za rekonstrukciju svih konstrukcija zgrade u cilju dostizanja vrednosti U - koeficijenta koje ispunjavaju uslove Pravilnika o energetskoj efikasnosti zgrada, potrebna su velika ulaganja. Sa aspekta investicija najbolje rešenje se vezuje za izmenu krovne konstrukcije. Ovaj rad je deo istraživanja koje je vezano za analizu potrošnje toplotne energije grejanih stanova usled smanjenja temperature vazduha ili negrejanja susednih stanova jedne stambene zgrade.

Ključne reči: *mere uštede energije; potrošnja toplotne energije; simulacija*

In this paper the analysis of implementation of energy saving measures in an existing residential building was conducted. Simulation of the energy behavior of the residential building, with useful heating area of 1247,68 m2, was performed by using software EnergyPlus. Six proposed measures was analyzed: replacement of windows and doors (case 1); change of the roof construction (case 2); change of the ground floor and ceiling constructions (case 3); change of the interior walls between different users (case 4); change of the interior walls toward unheated space (case 5) and implementation of all previously mentioned measures (case 6). The simulation results indicate that the average savings of heating energy of analyzed biulding are, respectively: 12,71% (case 1); 9,35% (case 2); 5,2% (case 3); 0,56% (case 4); 2,04% (case 5) and 29,37% (case 6). For reconstruction of all building constructions in order to achieve the value of U - coefficient that meets the Regulations on energy efficiency of buildings, a large investments are needed. In terms of investments the best solution is related to the change of the roof construction. This

paper is a part of investigation that is related to the analysis of heating consumption in heated apartments during the reduction of air temperature or unheating of adjacent apartments of an residential building.
Keywords: *energy saving measures; heating consumption; simulation*

Introduction

Averagely 65% of final energy consumption in Serbia is consumed for heating, which is close to the European average [1]. Unfortunately, the most of these apartments were built until 1980 as a part of the building within the urban areas. These buildings are characterized by oversized heating systems, lack of insulation and high specific heating consumption [2]. According to the scarce information about the specific heating consumption in the residential sector in Serbia, for space heating and heating of a domestic hot water in apartments in Serbia an average of 220 kWh/m2a is consumed, which is far more than the average in the EU [3]. The most common measures taken in order to increase energy efficiency and thereby reduce emissions of greenhouse gases are: insulation of a building, replacement of dilapidated windows and doors and installation of measuring and regulating devices (heat meters and thermostatic valves). The objective of this paper is reffered to the analysis of energy saving measures for existing residential building. Analysis was performed comparing the building with existing constructions and building with implemented energy saving measures that are related to: replacement of windows and doors, change of the roof construction, change of the ground floor and ceiling constructions, change of the interior walls between different users and change of the interior walls toward unheated space.

Description of the residential building

The total area of the analyzed residential building is 1504 m^2 and useful heating area 1247.68 m^2. The building has a total of 24 apartments distributed on 4 levels (Fig. 1). Distribution of apartments per levels is given in Fig. 2.

The physical characteristics of the building constructions (the values of the heat transfer coefficient of walls, window, roof, etc.) are given in Table 1 while the characteristics of materials of the added layers are given in Table 2. Only construction of the exterior wall meets the Regulations on energy efficiency of buildings (Table 3). The layers added to the building constructions are bolded as well as new obtained values for *U* - coefficient.

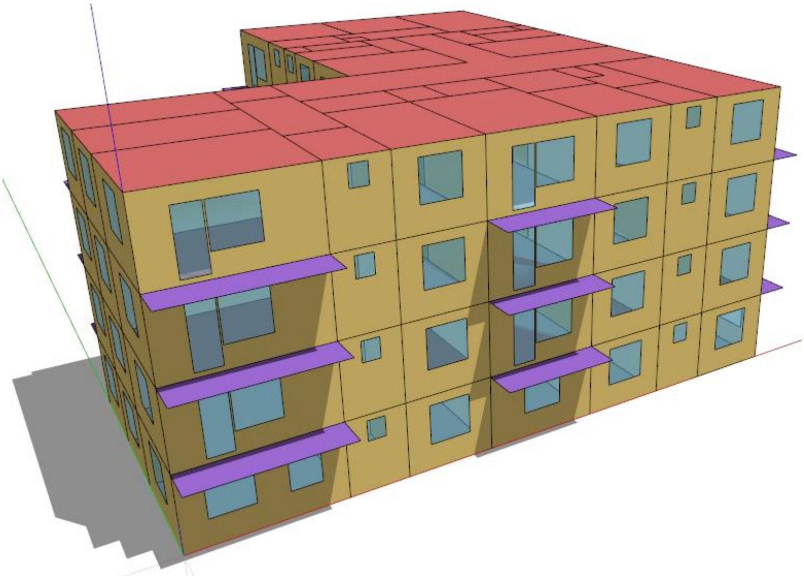

Fig. 1 *Isometric view of the analyzed residential building*

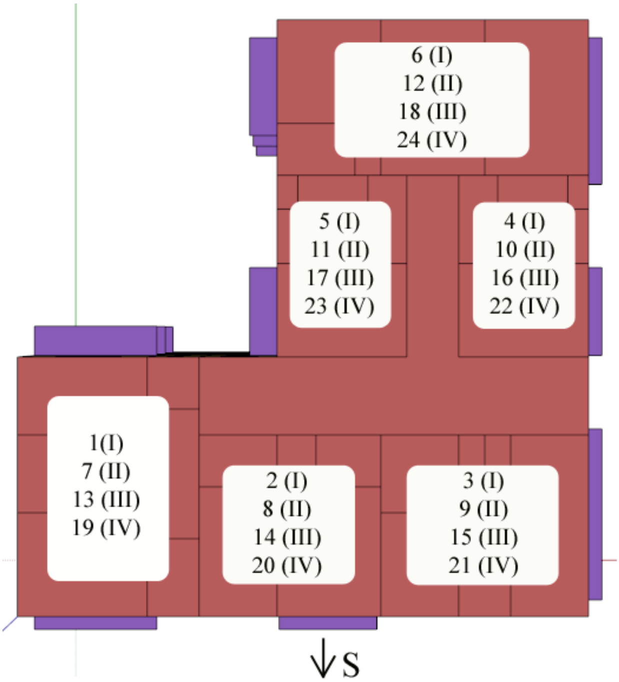

Fig. 2 *Distribution of apartments per levels of the analyzed residential building*

Table 1 The characteristics of the building constructions

Construction	Layer	U [W/m2K]
Window and balcony door	Glass (0.3 cm), Air (1.3 cm), Glass (0.3 cm); Glass (0.6 cm), Xenon (1.6 cm), Glass (0.6 cm), Xenon (1.6 cm), Glass (0.6 cm)	2.72; 1.5
Exterior door	Wood (3.5 cm); Wood (2 cm), Cellulose fibers (2 cm), Wood (2 cm)	4; 1.27
Exterior wall	Brick (12 cm), Expanded polystyrene foam (15 cm), Air (2 cm), Clay block (25 cm), Lime mortar (2.5 cm)	0.22
Interior wall	Lime mortar (2.5 cm), Brick (12 cm), Lime mortar (2.5 cm)	2.17
Interior wall between different users	Lime mortar (2.5 cm), Expanded polystyrene foam (1.5 cm), Brick (12 cm), Expanded polystyrene foam (1.5 cm), Lime mortar (2.5 cm)	2.17; 0.81
Interior wall toward unheated space	Lime mortar (2.5 cm), Brick (12 cm), Expanded polystyrene foam (6 cm), Lime mortar (2.5 cm)	2.17; 0.51
Roof	Gravel (5 cm), Waterproofing (0.5 cm; 1.5 cm), Mineral wool (12 cm), Cotton (5 cm), Vapor barrier (0.5 cm), Lightweight concrete 1 (5 cm), Lightweight concrete 2 (4 cm), Lightweight concrete 3 (16 cm), Lime mortar (2.5 cm);	0.51; 0.19
Floor with tiles	Stone (25 cm), Gravel (5 cm), Lightweight concrete 2 (4 cm), Waterproofing (0.8 cm), Lightweight concrete 2 (4 cm), Expanded polystyrene foam (8 cm), Waterproofing (1 cm), Ceramic tile (1.5 cm)	1.68; 0.38
Floor with hardwood	Stone (25 cm), Gravel (5 cm), Lightweight concrete 2 (4 cm), Waterproofing (0.8 cm), Lightweight concrete 2 (4 cm), Expanded polystyrene foam (8 cm), Waterproofing (1 cm), Hardwood (2 cm)	1.46; 0.37
Interior ceiling (with tiles)	Lime mortar (2.5 cm), Lightweight concrete 3 (16 cm), Lightweight concrete 2 (4 cm), Expanded polystyrene foam (3 cm), Waterproofing (1 cm), Ceramic tile (1.5 cm)	2.06; 0.76
Interior ceiling (with hardwood)	Lime mortar (2.5 cm), Lightweight concrete 3 (16 cm), Lightweight concrete 2 (4 cm), Expanded polystyrene foam (3 cm), Waterproofing (1 cm), Hardwood (2 cm)	1.77; 0.71

Table 2 *The characteristics of materials of the added layers*

Material	Thickness δ [m]	Density ρ [kg/m3]	Specific heat c [J/kgK]	Thermal transmittance coefficient λ [W/mK]
Waterproofing	0.01	1100	1050	0.17
Expanded polystyrene foam	0.015; 0.03; 0.06; 0.08	30	1260	0.041
Mineral wool	0.12	180	840	0.039
Cellulose fibers	0.02	85	1800	0.04

Table 3 *Maximum acceptable values for heat transfer coefficient, U_{max} [W/(m^{2}K)],for building constructions [4]*

Building construction	Existing building Umax [W/m2K]	New building Umax [W/m2K]
Exterior wall	0.4	0.3
Walls and ceiling constructions between heated spaces of the different units, different users	0.9	0.9
Flat roof above heated space	0.2	0.15
Windows, balcony doors of the heated spaces and heated winter gardens	1.5	1.5
Exterior door	1.6	1.6
Wall toward unheated space	0.55	0.4
Floor on the ground	0.4	0.3

The most apartments consists of: living room, bedroom, kitchen and bathroom. It is assumed that the building is not surrounded with any object. Use of lighting, electric equipment and occupancy in the building is defined by the schedules within the software EnergyPlus. Total number of people that accommodates each appartment is 4. During the interval of 8 to 16 h there is no presence of people. Total power of lighting and electric equipment is approximately the same for every appartment.

The building is heated by hot water from the heating system that consists of a boiler on natural gas, convective baseboard heaters and variable flow pump. The water convective baseboard heaters are put in each of the heated rooms. The heating system operates each day of the heating season from 15th of October to 15th of April.

During the day, they operates from 7:00 am to 9:00 pm, if the room temperature is below 20°C (22°C), from 9:00 pm to 12:00 pm if the room temperature is below 18°C and from 12:00 pm to 7:00 am if the room temperature is below 15°C. Air temperatures in the heated rooms are set to 20 °C for living room, bedroom and kitchen and 22 °C for bathroom.

Results and discussion

To simulate energy behavior of the analysed building, software EnergyPlus (version 7.1.0) was used. EnergyPlus takes into account all factors that influence thermal loads in the building, such as electricity devices, lighting, people in the building, solar radiation, wind, infiltration, and shading of open rooms [5, 6]. In this direction, the complex schedules of heating and cooling can be defined together with schedules for use of lighting, internal energy devices and occupancy in the building.

This paper is related to the analysis of implementation of energy saving measures in an existing residential building. Six measures was proposed and analyzed: replacement of windows and doors (case 1), change of the roof construction (case 2), change of the ground floor and ceiling constructions (case 3), change of the interior walls between different users (case 4) and change of the interior walls toward unheated space (case 5). Case 6 is related to the situation when all previously mentioned measures would be implemented.

Case 1 - Replacement of windows and doors

The heating consumption of the analyzed building before (Baseline case) and after possible reconstruction (case 1) is presented in Fig. 3. It can be concluded that first six appartments, on the ground floor (first level), have identical change of heating consumption as appartments on the upper levels. This pattern does not include the largest appartments on the level (1, 6, 7, 12, 13, 18, 19 and 24). These appartments have the highest heating consumption in the building because they have the highest number of exterior surfaces. On the other side, the appartments with the lowest heating consumption are 2, 8, 14 and 20. They have the lowest number of exterior surfaces (only one).

The percentage savings of heating energy are presented in Fig. 4. By replacing the balcony doors and windows (U = 1.5 W/m^{2}K) and exterior door (U = 1.27 W/m^{2}K) it can be saved 8 to 17% of heating energy. The average heating consumption of the building for this case would decrease form 40.97 to 35.81 kWh/m^2 and average percentage savings of heating energy would be 12.71%.

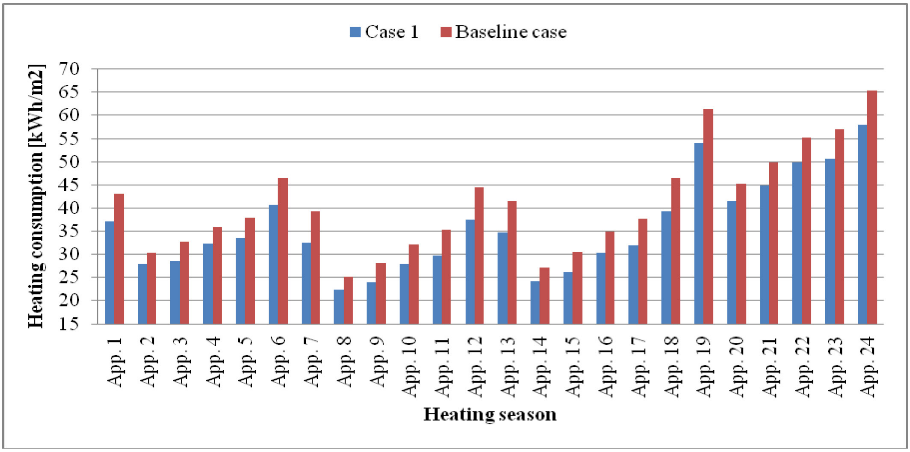

Fig. 3 *Heating consumption of the analyzed building for Baseline case and case 1*

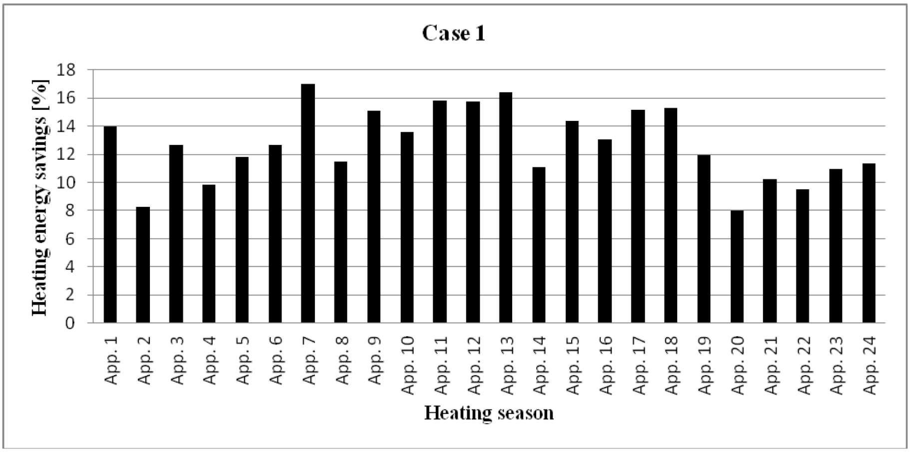

Fig. 4 *Percentage heating energy savings of the analyzed building for case 1*

1.1 Case 2 - Change of the roof construction

Change of the roof construction is reffered to the addition of the hydro insulation (waterproofing (1.5 cm)) and thermal insulation (mineral wool (12 cm)). By adding this layers the *U* - coefficient changed form value of 0.51 to 0.19 W/m^{2}K. The percentage heating energy savings for this case are presented in Fig. 5.

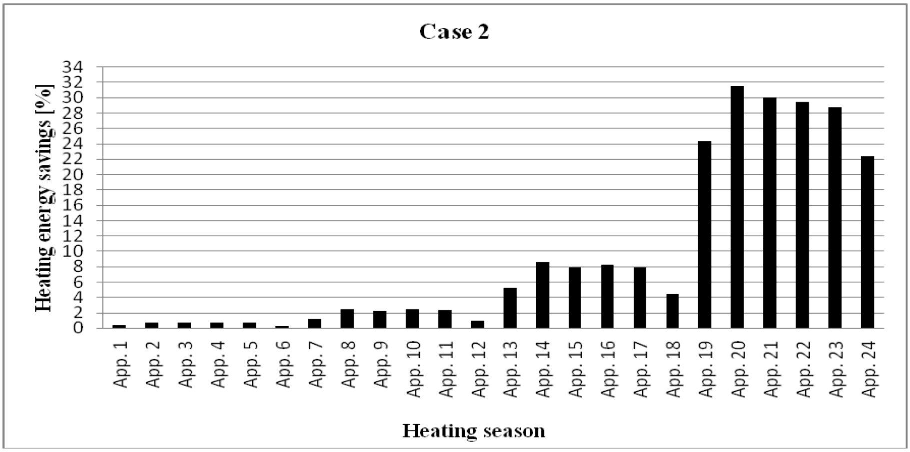

Fig. 5 *Percentage heating energy savings of the analyzed building for case 2*

The highest energy savings would appear on the highest (fourth) level (27.76%) which is in direct contact with roof construction. The change of this construction would lead to the decrease of the heating consumption on the other levels. The average percentage savings of heating energy for this case would be 9.35%.

1.2 Case 3 - Change of the ground floor and ceiling constructions

There are two types of floor and ceiling constructions. One includes hardwood layer and the other one layer of tiles. Hardwood is placed in hallways, living room and bedrooms while the layer of tiles is mounted in kitchens and bathrooms.

By adding the thermal insulation (expanded polystyrene foam (8 cm)) and hydro insulation (waterproofing (1 cm)) the *U*-coefficient change its value from 1.46 to 0.37 W/m^{2}K for floor with hardwood and 1.68 to 0.38 W/m^{2}K for floor with tiles. The ceiling construction is changed by adding the same insulation layers but with different thickness: expanded polystyrene foam (3 cm) and waterproofing (1 cm). The value of *U*-coefficient drops from 1.77 to 0.71 W/m^{2}K for ceiling with hardwood and 2.06 to 0.76 for ceiling with tiles.

The percentage heating energy savings for case 3 are presented in Fig. 6.

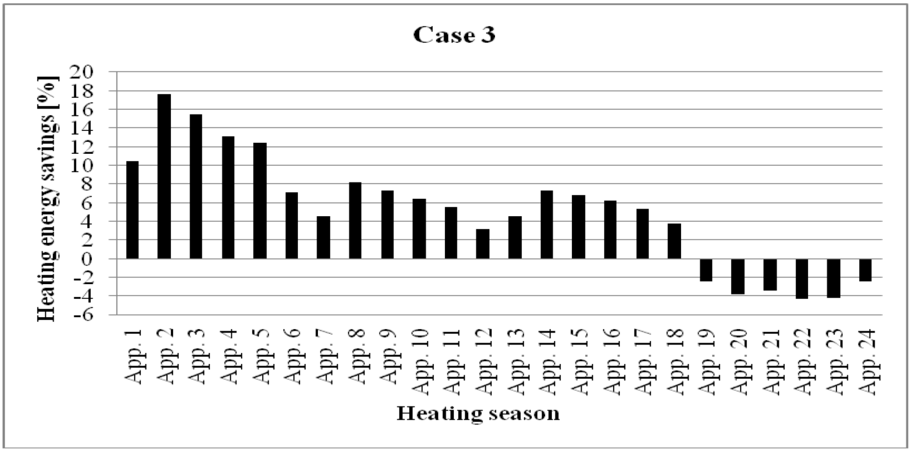

Fig. 6 *Percentage heating energy savings of the analyzed building for case 3*

The highest energy savings would be achieved on the first level (12.69%) because of its direct contact with ground. Because of the slower cooling of appartments on this level and lower heat transfer rate through the ceiling constructions the decrease of heating consumption would be achieved on the second and third level, too. On the other side, in appartments of the highest level the increase of heating consumption would occur (-3.42%), as a consequence of its position in the building (last level) and decrease of U - coefficient of ceiling construction. The average percentage savings of heating energy for this case and building would be 5.2%.

Case 4 - Change of the interior walls between different users

The term interior wall between different users is reffered to all walls that separate two different users (tenants) or appartments. The U - coefficient for these walls is changed from value 2.17 to 0.81 by adding two layers of thermal insulation (expanded polystyrene foam) with thickness of 1.5 cm. The percentage heating energy savings for case 4 are presented in Fig. 7.

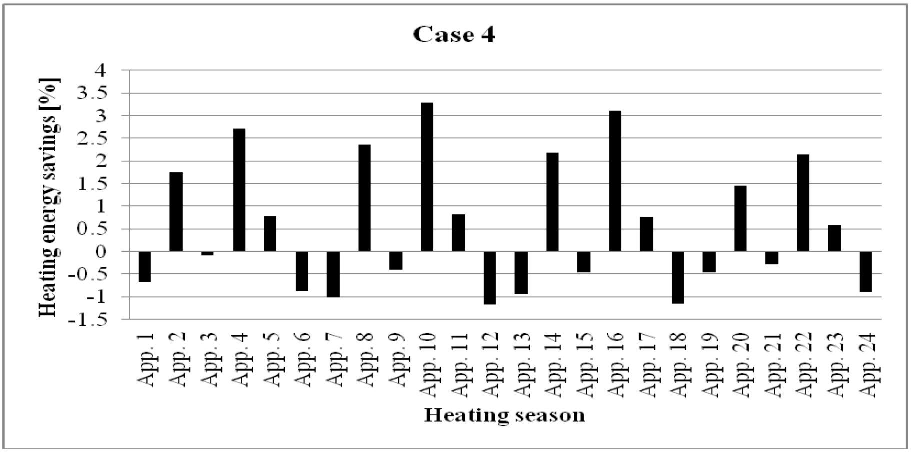

***Fig.** 7 Percentage heating energy savings of the analyzed building for case 4*

Also, in this case it can be noticed that heating consumption in some appartments decrease and in some appartments increase. The increase is recordered in appartments that have the most exterior surfaces (1, 3, 6, 7, 9, 12, 13, 15, 18, 19, 21 and 24). The change of interior wall construction would lead to the decrease of heat transfer rate through these walls and in relation to that decrease of heat gains of these appartments. The average percentage savings of heating energy for this case 4 would be 0.56%.

Case 5 - Change of the interior walls toward unheated space

Unheated spaces of the analyzed building are related to the pantries (storage rooms) and building hallways. The appartments that does not include pantry are: 1, 2, 7, 8, 13, 14, 19 and 20. The Regulations on energy efficiency of buildings indicates that the maximum value of *U* - coefficient (for an existing building) has to be 0.55 W/m^2K (Table 3). For the analyzed building (before possible reconstruction) the value of this parameter is 2.17 W/m^2K. In order to achieve value of *U* - coefficient that is less than value of 0.55 W/m^2K the interior wall has to be insulated with 6 cm of expanded polystyrene foam. The new obtained value for this parameter would be 0.51 W/m^2K. The percentage heating energy savings for case 5 are presented in Fig. 8.

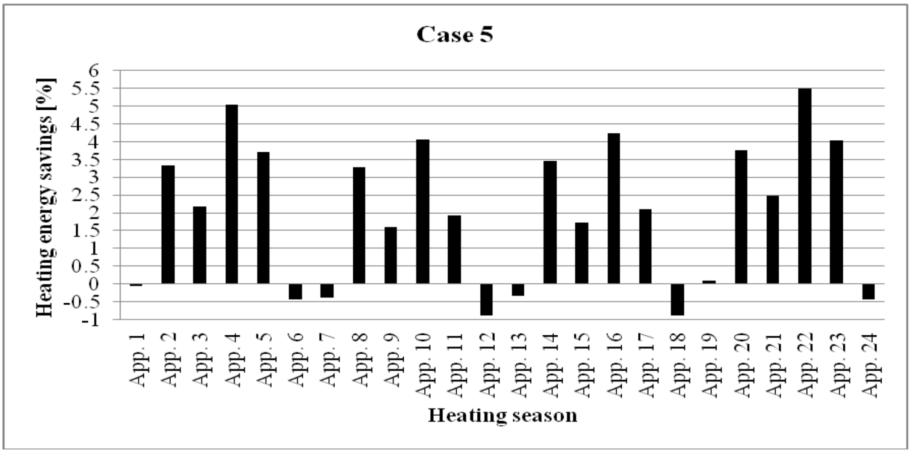

Fig. 8 *Percentage heating energy savings of the analyzed building for case 5*

As well as in the previous case, there is increase and decrease of heating consumption in certain appartments. The highest increase is noticed in the appartments that have the most exterior surfaces, pantry and the lowest area of the interior walls toward unheated space. On the other side, the decrease of heating consumption is reffered to the appartments that have large area of the interior wall toward unheated space. The average percentage savings of heating energy for this case 5 would be 2.04%.

Case 6 - Implementation of all previously mentioned measures

Case 6 includes a situation when all building constructions would have a value of U - coefficient that meets the Regulations on energy efficiency of buildings. In other words, this case represents possible implementation of all previously mentioned measures. In relation to that, the average heating consumption of the building would be 28.67 kWh/m^2 and the average percentage savings of heating energy would be 29.37% (Fig. 9).

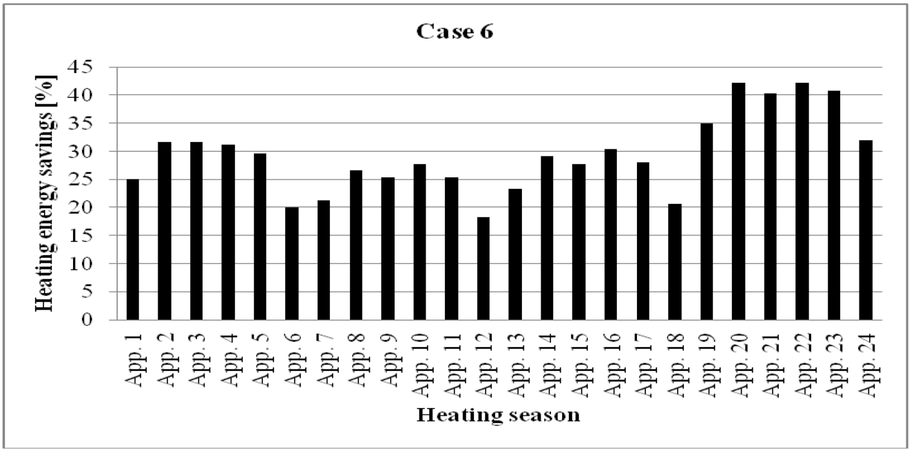

Fig. 9 *Percentage heating energy savings of the analyzed building for case 6*

The highest energy savings would be achieved on the last level (38.7%) and first level (28.17%) of the building. For the second and third level of the building heating energy savings would be 24.09% and 26.5%, respectively.

Conclusions

In this paper the analysis of implementation of different energy saving measures in an existing residential building was conducted. Simulation of the energy behavior of the residential building, with useful heating area of 1247.68 m^2, was performed by using software EnergyPlus. Six proposed measures was analyzed: replacement of windows and doors (case 1); change of the roof construction (case 2); change of the ground floor and ceiling constructions (case 3); change of the interior walls between different users (case 4); change of the interior walls toward unheated space (case 5) and implementation of all previously mentioned measures (case 6). The simulation results indicate that the average savings of heating energy of analyzed biulding are, respectively: 12.71% (case 1); 9.35% (case 2); 5.2% (case 3); 0.56% (case 4); 2.04% (case 5) and 29.37% (case 6). For reconstruction of all building constructions in order to achieve the value of *U* - coefficient that meets the Regulations on energy efficiency of buildings, a large investments are needed. In terms of investments the best solution is related to the change of the roof construction. According to the obtained results the highest energy savings, for case 6, would be achieved on the last level (38.7%) and first level (28.17%) of the building. This paper is a part of investigation that is related to the analysis of heating consumption in heated apartments during the reduction of air temperature or unheating of adjacent apartments of an residential building.

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References

[1] **Jovanovic, V., Stieldorf, K.,** Influence of Energy Prices and Income Inequalities on Retrofit Strategies in Developing Countries: Comparative Analysis of Cost-efficiency of Retrofits on Case Studies in Belgrade, Niš and Vienna, Proceedings - 8. Internationale Energiewirtschaftstagung (IEWT), TU Wien, Vienna, Austria, 2013.

[2] **Lukić, N., Jurišević, N., Nikolić, N., Gordić, D.,** Specific heating consumption in the residential sector of Serbia-Example of the city of Kragujevac, Energy and Buildings, Vol. 107 (2015), pp. 163-171.

[3] **Todorović, M.,** First NEEAP/BS national energy efficiency action plan/building sector 2009-2018: Study Report and NEEAP-BS for the Republic of Serbia Ministry of Mining and Energy, Washington: IRG, 2010.

[4] *** Pravilnik o energetskoj efikasnosti zgrada, Ministarstvo građevinarstva, saobraćaja i infrastrukture Republike Srbije, 2011.

[5] **Bojić, M., Nikolić, N., Nikolić, D., Skerlić, J., Miletić, I.,** Toward a positive-net-energy residential building in Serbian conditions, Applied Energy, Vol. 88 (2011), pp. 2407-2419.

[6] **Bojić, M., Nikolić, N., Nikolić, D., Skerlić, J., Miletić, I.,** A simulation appraisal of performance of different HVAC systems in an office building, Energy and Buildings, Vol. 43 (2011), pp. 1207-1215.